RESEARCH ARTICLE

CBR Predictive Model Development from Soil Index and Compaction Properties in case of Fine-Grained Soils of Debre –Tabor City, Ethiopia

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ABSTRACT: California Bearing Ratio is used for the evaluation of subgrade strengths during design of flexible pavements. However, determination of CBR value is time consuming, tedious, costly and laborious which highly affects the schedule of projects. To make a preliminary assessment of the suitability of soils required for a project, it is important to develop a prediction model for these engineering properties on the basis of laboratory tests which are quick to perform, less time consuming and cheap such as the tests for index properties of soils. This research evolves developing an efficient, simplified California Bearing Ratio (CBR) predictive model from soil index and compaction properties of fine-grained soils. The laboratory results indicated that samples used in this research lie in MH categories based on USCS and in the range of group A-7-5(16-65) based on AASHTO classification system. NCSS-12software is employed to investigate the significance of individual independent variables with the soaked CBR. One best model from each category with a very good statistical goodness of fit measures was selected. The developed models were validated against primary data. Moreover, the newly developed models are found to be by far better and can be used as a simple convenient tool to predict the CBR value of fine-grained soils in the study area. Among the various parameters derived from index properties and compaction characteristics, the Liquid Limit and Maximum Dry Density were found to be the most effective predictive parameter with R^2 = 0.899. The comparative results showed that the variation between the experimental and predicted results for CBR falls within 7.86% confidence interval which is by far better than other empirical equations reviewed in this paper.

KEYWORDS: CBR Value, Soaked, Fine-Grained Soils, Index Properties, Compaction, NCSS-12

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INTRODUCTION

Currently, many roads construction projects and railway constructions are undergoing in our country, Ethiopia [1]. The development of any country can be monitored by the progress in infrastructural facilities, with particular reference to road construction [2]. Road is necessary for transportation and economic development of a nation [3]. All civil engineering works such as the construction of highway, building structure, dam and other structure have a strong relationship with soil [4]. The unique nature of soil properties as it appears naturally is that being divergent spatially and seasonally beyond our control [3,5]. Every man-made structure resting on the ground needs safe and stable soil. To attain this safety and stability requirements the engineering properties of the soil beneath the structure or on the structure must be identified. However, obtaining these engineering properties of soils requires relatively more time and money [1].

Geotechnical engineers usually attempt to develop empirical correlations specific to a certain region and soil type [6]. However, these empirical equations are more applicable for the type of soil where the correlation is formulated. Hence, it is important to develop empirical correlation that best fit for the intended local area [7].The performance of pavement depends to a large extent on strength of sub grade material [8]. The sub grade is a layer of natural soil, prepared to receive the layers of pavement [9]. Subgrade should be strong enough to take up the stresses imposed due to loads without shear failure and excessive deformation [10,11]. The design and behavior of a flexible pavement depends mainly on the stability of the subgrade soil, which can be increased by compaction at optimum moisture content (OMC) and maximum dry density (MDD) [12]. There are various methods of design of flexible pavement, the most common being the California bearing method (CBR) which is an empirical method [9,13,14].CBR is expressed as the percentage ratio of unit load P that has to be

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applied so that a standard circular piston may be pressed in to soil sample at a rate of 1.25-mm/min. and standard load. The sub base / base thickness is governed by the CBR value of sub grade [9,15]. CBR test is a common laboratory test, performed to evaluate the shear strength and stiffness modulus of sub grade for the design of pavement. CBR test is a laborious test, therefore, it is vital to develop the models for quick assessment of CBR value [7,16,17].

The CBR test is essentially a penetration test, which can be carried out either in the laboratory or in the field [18]. In road construction civil engineers always encounter difficulties in obtaining representative CBR value for design of pavement because of time and cost. The type of soil is not the only parameter which affects the CBR value, but it also varies with different soil properties possessed by the soil [19]. Some countries like UK, the CBR test is no longer widely used, because pavement design carried out based on the observed performance of pavements, in the UK (Road Research Laboratory,1970) allows the CBR value to be obtained from particle size or plasticity index [20].

To acquire CBR estimation of a soil specimen, it takes about seven days, making CBR test costly, tedious and laboratory [3,6]. The method of evaluating CBR is standardized in AASHTO T 193 and ASTM D 1883 and the value of CBR is an indicator of the suitability of natural subgrade soil as a construction material [21]. It is to be noted that CBR test is widely accepted internationally as a reliable method of pavement design and is also used in soil classification of base and subbase (road base) materials for highway designs and construction [11,12].

To simulate worst moisture condition of the given soil, soaked California Bearing Ratio value is used in the design of pavements [3,16,22]. To obtain soaked CBR value of a soil sample, it takes about a week, making CBR test expensive, time consuming and laborious [13,16,21,23]. So, in this aspect indirect methods play useful role in supporting the quality of estimation of CBR values [24]. According to Roy [16] the CBR is affected by the type of soil and different soil properties. Its prediction using index properties of soils can be the alternate method for the time-consuming test like CBR. Index properties have wide applications in geotechnical engineering practice and a number of index properties which are easily recognized in soil mechanics have been outlined by many authors [11,25].It is reasonable to assume that California Bearing Ratio (CBR) values are related to soil index properties in some ways [26]. Soil compaction improves the physical and mechanical properties of soil thus causing an increase in its shear strength and bearing capacity, decrease in future settlement of soil & decrease in its permeability [12]. CBR depends on many factors like maximum dry density, optimum moisture content, liquid limit, plastic limit, plasticity index, type of soil [14,16].

From visual identification Debre Tabor soil indicates that weathered and hard rock, expansive and non-expansive fine-grained soil is dominantly found as a natural soil in the city. Hence, this study focuses on developing the intended correlation for different distributions of suitable subgrade soils, specifically fine-grained soils, which represents the study area. From this, soaked CBR is correlating with compaction (Optimum Moisture Content and Maximum Dry Density) and index properties (Liquid Limit, Plastic Limit, Plasticity Index, % of fine, Specific Gravity and water content) by using NCSS model.

The outcome of this research can be applicable for preliminary investigations of subgrade construction of road projects in and around the city. It can also helpful for any organization that need to know the index properties, compaction properties and predictive CBR model of socked CBR values of the area for constructing different civil infrastructures.

Study Area

DebereTabor is found in northern part of Ethiopia at 667 km distance from Addis Ababa toward North West direction of the country and 50 kilometers to east of Lake Tana.

It is situated about 97 km from Bahir Dar city toward the east direction and about 100 kilometers southeast of Gondar. The specific geographic grid reference location of the study area is bounded between 11°51′N and 38°1′E with a total area about3187.07 hectare as shown in Figure 1.

In order to have sufficient and reliable data for the target analysis, laboratory tests were conducted on soil samples obtained from different locations of Debre Tabor city, mainly from northern parts of the area.

Researchers collected soil samples from the depths between 40 cm and 150 cm after removing the topsoil whereas others collected the samples from 91.4 cm depth to assess the strength of subgrade soil. But it is possible to get acceptable quality of soils within 60 cm depth from the ground level, which can be used in the subgrade and even in subbase/base courses [16].

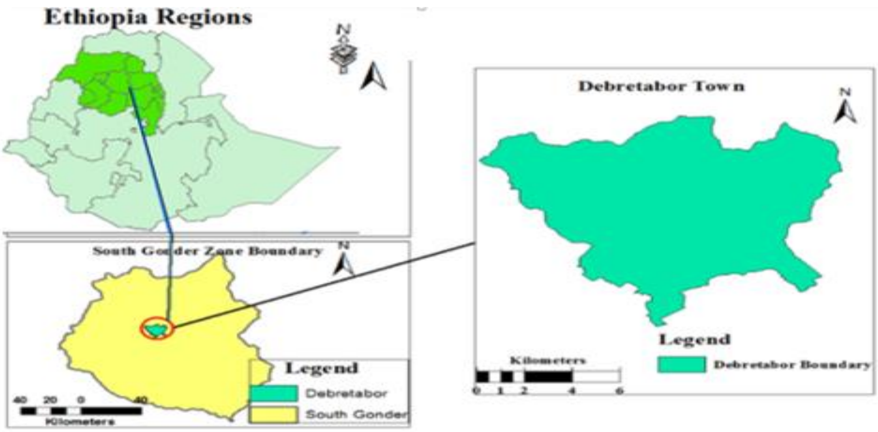

Figure 1: Map of the study area

Before samples are collected, a reconnaissance survey was conducted to visually identify the fine soil locations, and locate borrow pit point. From these pits a total of 15 disturbed soil data were collected with a distance of about 1 km radius and a depth of varying from 1.2 to 1.9m below the ground surface for model development and another 3 samples are collected for calibration/validation of the model as shown in [Table 1] below.

RESULTS AND DISCUSSION

Fifteen numbers of disturbed soil samples were collected from different locations from in and around the city of Debre Tabor district. The selected soil samples were tested for socked CBR value, optimum moisture content, maximum dry density, particle size distribution, liquid limit, plastic limit and plasticity index. All these tests were performed according to the following code of specification.

Table 1: Location and depth of samples

Pit Number	Depth(m)	Location
1	1.2	Weibla
2	1.4	Kegawuha
3	1.5	Fert School
4	1.4	FekedeEgzi College
5	1.5	Ajibar Stadium
6	1.6	Janmeda
7	1.5	Abaregay
8	1.7	Near DTU
9	1.4	Zufil
10	1.8	Higher academy
11	1.65	Near Kidanemhiret
12	1.75	Poly technic college
13	1.5	Emaliya
14	1.6	HamusGebeya
15	1.9	Asfaw Girar

The laboratory results of various soil properties for fifteen soil samples are summarized and presented in Table 2.

- Natural moisture content (ASTM D 2216)
- Specific gravity (ASTM D 854)
- Grain size Analysis Test (ASTM D 422)
- Liquid Limit Test (ASTM D 4318)
- Plastic Limit Test (ASTM D4318)
- Modified Proctor Test (ASTM D 1557)
- CBR Test (ASTM D 1883)

Model Development

Researchers developed various correlation models to predict CBR value from various soil properties, however, equations developed for soils in one place may not work at all if tested on soils of another place of the same region. Hence specific models have to be developed for specific areas in order to obtain good result.

Table 2 Results of Laboratory Test for Soil Samples

Test no	USCS	F %	S%	G%	LL%	PL%	PI%	MDD (g/cc)	OMC (%)	G_s	W%	LI	CBR%
1	MH	83.88	14.77	1.35	59.30	43.07	16.23	1.43	34.7	2.5	14.47	-1.79	8.56
2	MH	91.64	7.33	1.03	63.64	41.27	22.37	1.44	31.0	2.63	14.8	-1.14	4.69
3	MH	86.54	8.55	4.91	67.49	50.3	17.14	1.36	34.29	2.53	14.04	-2.78	8.45
4	MH	92.94	6.68	0.38	81.05	53.35	27.7	1.29	36.65	2.82	21.23	-1.13	7.93
5	MH	92.93	6.98	0.09	73.85	42.58	31.27	1.35	30.6	2.45	14.82	-0.91	6.65
6	MH	89.92	8.53	1.55	68.74	37.02	31.72	1.47	30.0	2.81	15.33	-0.68	4.80
7	MH	93.5	5.84	0.66	87.18	39.13	48.05	1.52	26.7	2.66	14.00	-0.52	2.90
8	MH	86.98	11.93	1.09	60.35	43.07	17.28	1.46	30.5	2.53	12.51	-1.79	5.23
9	MH	91.94	6.91	1.15	87.83	41.73	46.1	1.48	32.7	2.66	15.54	-0.58	3.00
10	MH	88.47	10.74	0.79	60.09	38.46	21.63	1.46	31.5	2.67	13.31	-1.13	7.10
11	MH	93.52	6.08	0.4	69	43.88	25.12	1.48	26.3	2.7	14.93	-1.16	3.04
12	MH	85.83	13.51	0.66	50.12	34.76	15.36	1.6	25.3	2.78	13.21	-1.45	6.57
13	MH	95.18	4.22	0.6	96.6	42.12	54.48	1.41	27.7	2.6	17.59	-0.44	3.38
14	MH	94.58	4.78	0.64	53.07	34.31	18.76	1.56	27.4	2.81	12.67	-1.11	7.47
15	MH	89.21	9.13	1.66	71.44	35.57	35.87	1.52	29.0	2.65	12.88	-0.66	5.55

Where: USCS-Unified Soil Classification System, F%-Percentage of fines, S%-percentage of Sand, G%-Percentage of Gravel, LL-liquid Limit, PL-Plastic Limit, PI-Plastic Index, MDD-Maximum Dry Density, OMM-Optimum Moisture Content, G_s-Specific Gravity, W%-Water Content, LI-Liquidity Index, CBR- California Bearing Ratio

For the quick estimation of CBR value, attempts shall made to correlate the CBR with the basic index and compaction properties of the soil [28]. These mainly include LL, PL and Gs, compaction characteristics such as MDD and OMC, grain size distribution analysis such as gravel (G%), sand(S%) [28]. It is a must to consider the compaction effect and water content which has a remarkable effect on California bearing ratio. Therefore, these two factors should be strictly controlled in the construction [9].

In this study, regression models, both simple linear regression analysis (SLRA) and multiple linear regression analysis (MLRA), were developed for estimating soaked CBR value using physical properties of soils.CBR values between 0 and 40 usually correspond to fine grained soils. In this case, the gravel content is not a determining factor in soil resistance compared with contents of plastics fine manifested as OMC [28]. The effect of moisture content on CBR value is significant [29]. It has been observed from Proctor Compaction test that Maximum Dry Density (MDD) for a soil is obtained at Optimum Moisture Content (OMC). OMC and MDD are the most important parameters influencing CBR [15].

Figure 2: Sampling and laboratory analysis

Fitting a regression model requires several assumptions [1]. The coefficient of determination is a quantitative measure to represent how well the predicted results are replicated by the model [30]. The value of R^2 is always between 0 and 1 because R is between -1 and +1, whereby a negative value of R indicates inversely relationship and positive value implies direct relationship. R^2 is probably the most popular statistical measure of how well the regression model fits the data value of R^2 near zero indicates no linear relationship between the dependent and independent variables, while a value near one indicates a perfect linear fit [1,28].

Nonlinear multiple regression with Subset selection and interaction analysis routines of NCSS-12 statistical software was used in the analysis to develop the line or curve which provides the best fit through a set of data points. The best fit model could be in the form of linear, parabolic or logarithmic trend. A linear relationship is usually practiced in solving different engineering problems because of its simplicity however the reality for soils is totally different [1].

Model Variables

In this analysis soaked CBR value obtained from tests are used as a dependent variable and the independent variables includes index properties like (LL, PL, and PI), data from sieve analysis (%fines) and results from modified compaction characteristics (MDD&OMC) and some other indicative variables.

In order to study the relationships developed between the dependent and independent variables so as to determine the model that best suits the test results, a scatter plot is verified using NCSS software as shown in Figure 3.

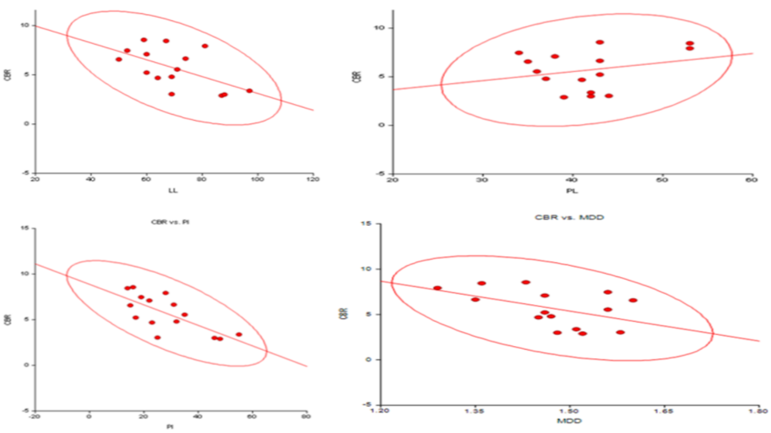

Figure 3: Scatter plot of CBR vs. some independent variable

Teklehaymanot & Alene

Results of normality check of percent of finer, liquid limit, plastic limit, plasticity index, maximum dry density and optimum moisture contents are presented in Figure 4 in normal probability plot.

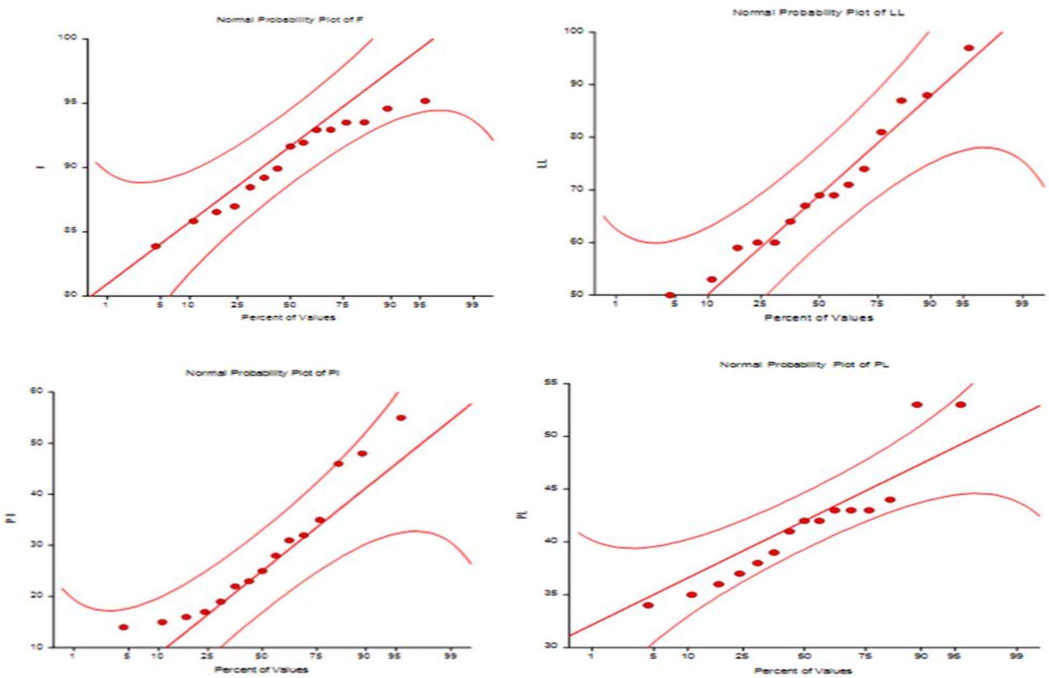

Figure 4: Normal probability plot for some variables

Goodness of Prediction Measures

The ultimate goal of the research is to find an appropriate mathematical model that expresses the relationship between a dependent variable, CBR, and several independent variables, and estimating the values of its parameters using linear and nonlinear multiple regression. Therefore, a convenient way of measuring how well the regression model performs as a predictor of the dependent variable is to compute parameters such as RMSE, R^2, Adj R^2, Coefficient of Variation, Mean Square Error and Ave Abs Pct Error.

Regression Result and Model Selection

Transforming the CBR value into four different forms and 12 different best fit models by considering intercept has been developed as a trial. The accuracy of results was based on the coefficient of correlation (Adj R^2) and coefficient of determination R^2 values [31]. Value of coefficient of determination R^2 indicates the representativeness of the model and the linear coefficient of correlation 'Adj R^2' is a measure of correlation strength between variables x and y. If $R^2>0.9$, the goodness of fit is excellent, if R^2it is from 0.7- 0.89, it is good, when R^2 is from 0.4-0.69, it is fair, if R^2 is from 0.2-0.39, it is poor and, in case, where $R^2<0.2$ it is very poor.

So, if the correlation coefficient is closer to one, the correlation became stronger [7,31]. According to Ksenija Djokovic [32] if Adj $R^2<0.30$ there was no significant correlation, if 0.5 <Adj $R^2<0.7$ correlation is significant, when 0.7 < Adj $R^2<$ 0.9 correlation is strong, in the case where Adj $R^2>$ 0.9 very strong correlation. So, if the correlation coefficient is closer to one, the correlation became stronger. Using NCSS-12 data analysis method the procedure output window generates the following best equations presented in Table 3.

To select the best model that provides a very good result depends on several factors, but the most important are; the number of parameters/variables included in the model must be minimum, the value of R^2 and AdjR^2 should be maximum i.e., approached to one, whereas Coefficient of variation, mean square error, square root of MSE, Ave Abs pct. Error and number of independent variables should be minimum when comparing to others [1].

From the criteria described above, models with more than three independent variables and

relatively lower R^2 and AdjR^2 value are not recommended to this model development work. Therefore Model [9,11,12] [Table 3&4] were compared to select the best fit CBR predictive model.

Table 3: Best fit models from each parameter

ase	Parameter	Best fit Model
C1 = CBR	1	$1.757+7.519\frac{EXP(3)}{MDD(PI+MDD^2)}$
	2	$-6.552+\frac{3.225}{ln(MDD)}+\frac{47700}{LL*PL*\sqrt{PI}}$
	3	$43.14-17.62\times Log(LL)+409.40\frac{(1.25-MDD)}{ln(MDD)\times(45-MDD)}$
C2 = log (CBR)	1	$0.398+0.625\times\frac{EXP(3)}{MDD(PI+MDD^2)}$
	2	$0.58+0.285(LI)+1.45\frac{.EXP(3)}{MDD(PI+MDD^2)}$
	3	$1.01-\frac{24.86}{LL}+0.699(LI)+3\frac{EXP(3)}{MDD(PI-MDD^2)}$
C3= $\sqrt{CBR}$	1	$1.496+48\frac{EXP(3)}{MDD(PI+MDD^2)}$
	2	$0.25+\frac{5.575}{MDD^3}+\frac{10575}{LL\times PL\times\sqrt{PI}}$
	3	$10.465-3.9459Log(LL)+81.247\frac{(1.28-MDD)}{ln(MDD)\times(45-MDD)}$
C4 = log (CBR+CBR^2)	1	$2.754-0.045\frac{(100-PL)\times LL}{150}$
	2	$-0.299+\frac{3.89}{MDD^3}+\frac{5362.88}{LL\times PL\times\sqrt{PI}}$
	3	$7.25-2.85Log(LL)+\frac{52.55}{ln(MDD)}-\frac{2296.8}{ln(MD)\times(45-MDD)}$

From the above discussion, the equation which is the best fit model [Model 9] developed as a function of maximum dry density (MDD) and Liquid Limit is selected and presented as [equation 1] below with value R^2=0.8994 and Adj R^2=0.872 as summarized in [Table 4] below:

$$\boldsymbol{CBR = 43.15-17.62\times Log(LL)+409.40\frac{(1.25-MDD)}{ln(MDD)\times(45-MDD)}} \qquad (1)$$

Where: CBR in%, MDD=Maximum Dry density in g/cc, LL= Liquid Limit in %. To evaluate the result obtained using [Model 9] between the actual and predicted CBR values, the linear regression plot analysis is done and summarized in Table 5and Figure 5.

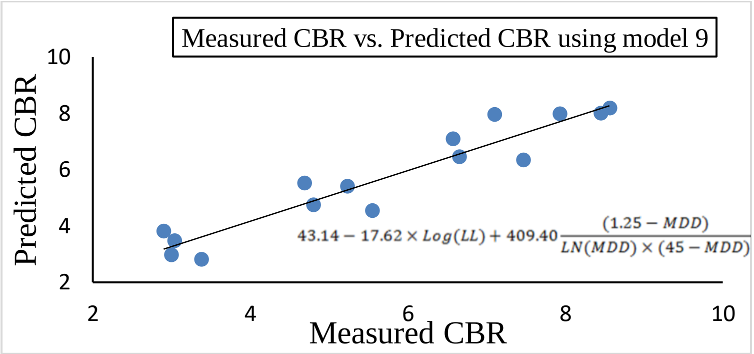

Figure 5: Predicted values with prediction limits of individual CBR data using Model 9

Table 4: Regression Summery Report for all Models

	Model No	Dependent Variable	R^2 value	Adj. R^2	Coe. of variation	Mean square Error	S. Root of MSE	Ave Abs.Pct. Error	Model Rank
1	1	CBR	0.5797	0.5474	0.2389	1.84675	1.3589	21.651	1
	2	Log (CBR)	0.5687	0.5356	0.1594	0.01337	0.1156	13.687	3
	3	√CBR	0.5731	0.5402	0.1271	0.08897	0.2982	10.720	2
	4	Log ($CBR+CBR^2$)	0.5674	0.5341	0.1383	0.04480	0.2116	11.613	4
2	5	CBR	0.7992	0.7657	0.1719	0.95615	0.9778	14.259	4
	6	Log (CBR)	0.8249	0.7957	0.1057	0.00588	0.0766	8.377	1
	7	√CBR	0.8127	0.7815	0.0876	0.04228	0.2056	6.665	3
	8	LOG($CBR+CBR^2$)	0.8216	0.7919	0.0924	0.02002	0.1414	7.076	2
3	9	CBR	0.8994	0.8720	0.1270	0.52221	0.7226	10.123	1
	10	Log (CBR)	0.8742	0.8399	0.0936	0.00461	0.0678	7.784	4
	11	√CBR	0.8952	0.8667	0.0684	0.02580	0.1606	5.124	2
	12	LOG($CBR+CBR^2$)	0.8895	0.8593	0.0760	0.01353	0.1163	5.804	3

Evaluation and Validation of the Developed and Existing Model

Previously various forms of empirical equations were proposed which relate CBR to certain physical properties of soils. Obviously, the proposed equations might have served their purpose in areas where they have been specifically developed. The suitability of existing correlations particularly the Leliso's and NCHRP's correlation along with the developed correlation is examined using a control test result obtained from the subject study area as shown in Table 6. This shows that the leliso's correlation result has an average variation of 29.10% from the actual CBR values [1] whereas, the NCHRP's correlation resulted an average variation of 45.96% [33]. On the other hand, the developed correlation by this work predicted the CBR value with an average variation of 7.84 % from the actual CBR value which is much better than others.

CONCLUSION

The results of the analysis indicate that there is a close relationship between the socked CBR values, Compaction and index properties of the fine-grained soil. The soils of the studied area are grouped on the range of A-7-5(16) as a good soil and A-7-5(65) with a poor soil as per AASHTO classification system. Moreover, as per USCS soil classification system all of the soil samples are grouped as MH (Inorganic silt with high plasticity). The CBR test results show that the values range from 2.90% to 8.56%, which implies the soil have a sub grade strength property of poor to good depending on location of the soil with in the study area. A comparative assessment between measured and calculated values of the CBR indicates that the developed equation provides good agreement with the measured values with an average variation of 7.84%. The statistical goodness of fit measure of CBR Prediction using this model is R^2 = 0.8994, Adj R^2 = 0.8720implying that the model is efficient. After validation and comparison of the newly developed CBR predictive model with control test data and other previous models, it would be noted that the newly developed CBR predictive model is more efficient than the existing model and better to be used for characterizing and estimating the strength of fine-grained soils of the study area. Therefore, the statistical parameters indicate that the model developed by regression analysis for correlating soaked CBR value with Maximum Dry Density (MDD) and Liquid Limit has shown a better performance. Therefore, the municipal administration of Debre tabor city, road contractors, and other organizations that need index property, compaction and soaked CBR value in the area can refer this paper.

Table 5: Predicted vales of individual Samples using [Model 9]

Row	Actual CBR%	Predicted CBR (%)	Standard Error of predicted	Row	Actual CBR%	Predicted CBR (%)	Standard Error of predicted
1	8.56	8.1833	0.8086	9	3.00	2.9768	0.8041
2	4.69	5.5189	0.7831	10	7.10	7.9644	0.8245
3	8.45	8.0016	0.7956	11	3.04	3.4707	0.7994
4	7.93	7.9881	0.8954	12	6.57	7.0882	0.8328
5	6.65	6.4684	0.8018	13	3.38	2.8198	0.8597
6	4.80	4.7393	0.7621	14	7.47	6.3429	0.8046
7	2.90	3.8145	0.8276	15	5.55	4.5393	0.7671
8	5.23	5.4039	0.8231				

Table 6: Developed and Existing Correlations

Test no	Developed Equation			Leliso'sEquation		NCHRP Equation	
	Actual CBR(%)	Predicted CBR (%)	Variation (%)	Predicted (%)	Variation (%)	Predicted (%)	Variation (%)
1	6.10	6.37	4.45	5.09	-16.63	6.09	-0.18
2	4.46	4.69	5.24	3.00	-32.68	8.68	94.52
3	5.60	4.83	-13.82	3.47	-38.00	3.18	-43.19

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